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“Nuclear physics aspects of the exotic μ -e conversion in nuclei”

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Outline

- Introduction
 - LF and/or L violating processes
 - Historical review on the μ -e conversion experiments
 - Motivation for studying FCNC processes
- Effective Transition μ -e Operators (nucleon, nuclear level)
 - ➡ Transition Matrix Elements (Nuclear Methods)
- Results and discussion (Shell Model, QRPA, Fermi Gas Model)
- Summary - Conclusions - Outlook

Lepton flavor non-conservation

1) Elementary L \bar{F} V processes:

$$\mu \rightarrow e\gamma, \quad \tau \rightarrow e\gamma, \quad \tau \rightarrow \mu\gamma$$

$$\mu \rightarrow ee^+e^- \quad (\mu \rightarrow 3e)$$

$$\tau \rightarrow ee^+e^-, \quad \tau \rightarrow \mu e^+e^-, \quad \tau \rightarrow e\mu^+\mu^-, \quad \tau \rightarrow \mu\mu^+\mu^-$$

$$\nu_e \rightarrow \nu_\mu \quad \nu_\mu \rightarrow \nu_\tau \quad \text{etc.} \quad (\text{neutrino oscillations})$$

2) Neutrinoless L \bar{F} V/L processes in Nuclei:

$$\mu_b^- + (A, Z) \rightarrow e^- + (A, Z)^* \quad (\mu^- \rightarrow e^- \text{ conversion})$$

$$\mu_b^- + (A, Z) \rightarrow e^+ + (A, Z - 2)^* \quad (\mu^- \rightarrow e^+ \text{ conversion})$$

$$(A, Z) \rightarrow (A, Z \pm 2) + e^\mp e^\mp \quad (0\nu\beta\beta - \text{decay})$$



$$e^- + (A, Z) \rightarrow (A, Z)^* + \mu^- \quad (\text{high-energy } e^- \rightarrow \mu^- \text{ conversion})$$

3) Exotic neutrino-nucleus processes ($FCNC$ processes)

$$\nu_\alpha + (A, Z) \rightarrow \nu_\beta + (A, Z)^*$$

$$(\alpha \neq \beta)$$

$$\tilde{\nu}_\alpha + (A, Z) \rightarrow \tilde{\nu}_\beta + (A, Z)^*$$

Impact to Astrophysics

P. Amanik, Ph.D (2006) [UC San Diego, USA]

D.K. Papoulias, TSK, in preparation

Motivation for studying FCNC processes

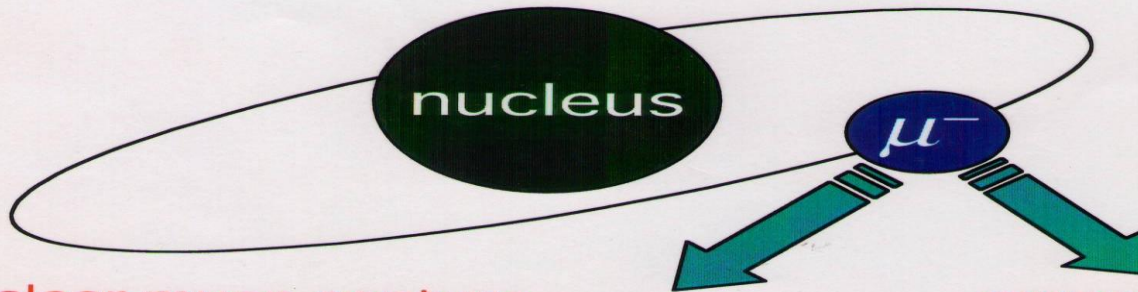
- Up to now there is no experimental evidence for FCNC in charged-lepton processes
 - The existing FCNC data refer to neutral leptons (**ν** -oscillations in propagation)
- ➡ **The FCNC interactions have not been completely understood up to now.**

The $\mu - e$ conversion puts stringent constraints on LFV parameters entering the non-standard Lagrangians (isoscalar, isovector couplings of all the current components, SUSY parameters, etc.)

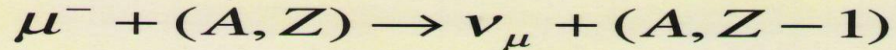
- Experimentally $\mu^- \rightarrow e^-$ and $\mu^- \rightarrow e^+$ are simultaneously studied
- Detection of only one particle (event) is sufficient (**NO coincidence is needed**)
- For the coherent mode, around $E_e \approx m_\mu - \epsilon_b$, (ϵ_b = μ -energy in 1s orbit), the signal of $\mu - e$, **the reaction is background free**

μ -e Conversion

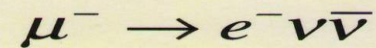
- muonic atom (1s state)



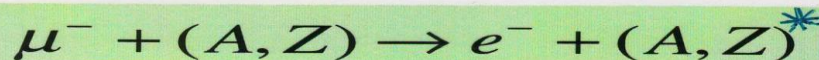
nuclear muon capture



muon decay in orbit



- neutrinoless muon nuclear capture
(= μ -e conversion)

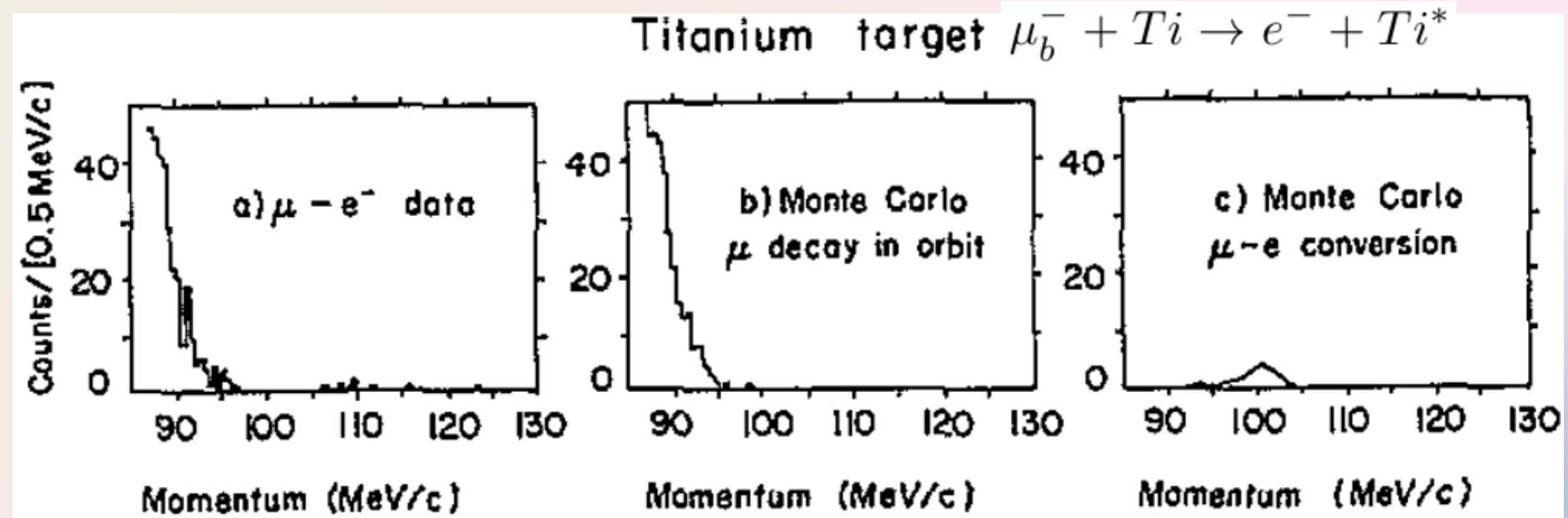


coherent process

lepton flavors
change by one unit

$$R(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

Electron spectrum measured at TRIUMF

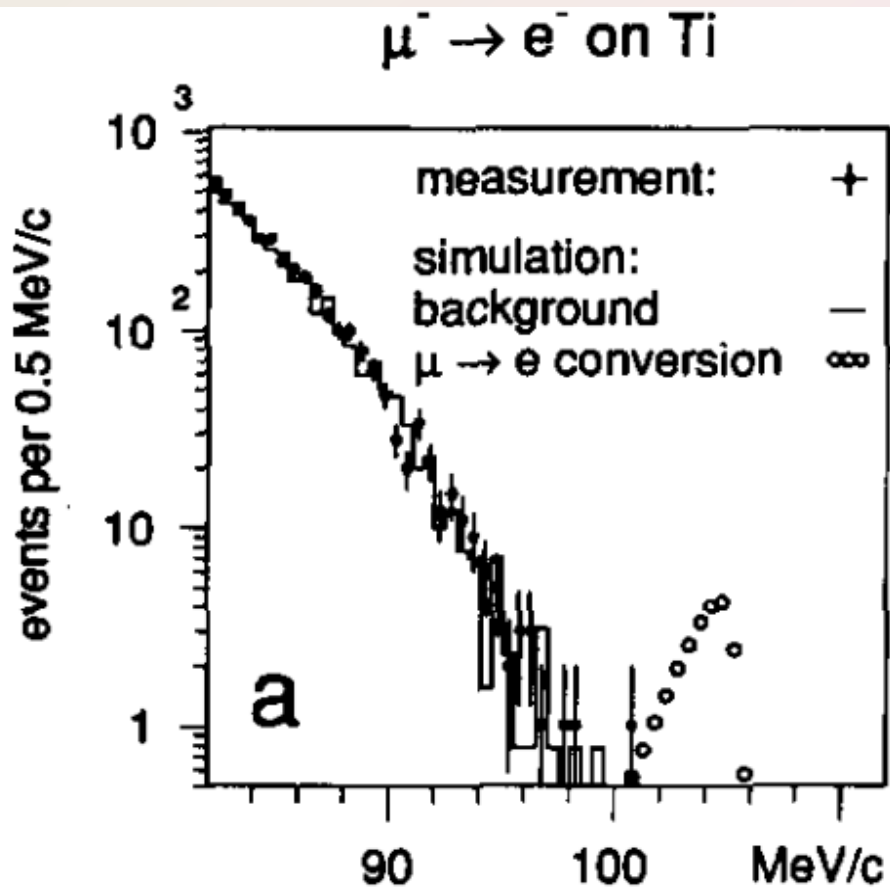


(a) Experimental e^- spectrum measured with TRIUMF TPC. (b) Monte Carlo simulation for MDIO. (c) Monte Carlo simulation of **mu2e conversion peak** for a branching ratio of 7×10^{-11}

[Depommier and Leroy, RPP 58 (1995) 61]

The observed spectrum agrees with the predicted one for MDIO in the energy range $87 < E < 95 \text{ MeV}$. No events found in the window $96.5 < E < 106 \text{ MeV}$. Events above 106 MeV cannot be due to μ -decay but cosmic-ray or pion-capture events

Electron spectrum measured at PSI



Measured electron spectrum in the SINDUM II experiment using Ti as stopping target.

No events were measured found in the energy window

$$100 \leq E_e \leq 106 \text{ MeV}$$

Energy region of $\mu 2e$ signal

[PLB 317 (1993) 631, SINDUM II Collaboration]

Upper limit :

$$R_{e-N} = \frac{\Gamma(\mu^- Ti \rightarrow e^- Ti(gs))}{\Gamma(\mu^- Ti \rightarrow \text{capture})} < 4.3 \times 10^{-12}$$

Short history of the heroic experimental effort to 'see' μ -e conversion events

1955: J. Steinberg, H. Wolfe, PR 100 (1955) 1490, Columbia Cyclotron,
first experiment for μ -e using Cu, $R_{\mu-e} < 5 \times 10^{-4}$

1961: M. Conversi et. al., PR 122 (1961) 687, CERN Cyclotron,
Two independent experiments using Cu, $R_{\mu-e} < 5 \times 10^{-5}$, $R_{\mu-e} < 5 \times 10^{-6}$

1972: D.A. Bryman et. al., PRL 28 (1972) 1469, TRIUMF colab.
TPC experiment with Cu target, $R_{\mu-e} < 2.6 \times 10^{-8}$

1982: A. Badertscher et. al., NPA 377 (1982) 406; NPA 368 (81) 438,
use of isoscalar ^{32}S target at SIN (PSI) $R_{\mu-e} < 1.6 \times 10^{-8}$

1985: D.A. Bryman et. al., PRL 55 (1985) 465, TRIUMF TCP experiment,
use of ^{48}Ti , $R_{\mu-e} < 1.6 \times 10^{-11}$

1988: S. Ahmad et. al., PRL 59 (1987) 970; PRD 38 (88) 2102, TRIUMF,
use of ^{48}Ti $R_{\mu-e} < 4.6 \times 10^{-12}$ and ^{208}Pb $R_{\mu-e} < 4.8 \times 10^{-10}$

1993: C. Dohmen et. al., PLB 317 (1993) 631, SINDRUM II colab.
Improved limit on the branching ratio using ^{48}Ti , $R_{\mu-e} < 4.3 \times 10^{-12}$

1996: W. Honecker et. al., PRL 76 (1996) 200, SINDRUM II colab.
Improvement of the limit for the ^{208}Pb target, $R_{\mu-e} < 4.6 \times 10^{-11}$

Best experimental limit on $R_{\mu e}$

The best upper limit on $R_{\mu e}$ comes from the SINDRUM II experiment (PSI) using ^{197}Au as stopping target

Bertl, W., et al. (2006), The European Physical Journal C - Particles and Fields 47, 337

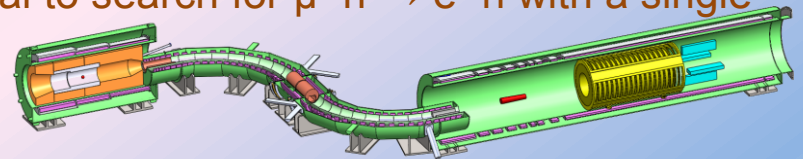
$$R = \frac{\Gamma(\mu^- \rightarrow e^-)}{\Gamma(\mu^- \rightarrow \text{capture})} \leq 5.0 \times 10^{-13}$$

Recent 'planned' experiments

1). Mu2e (FNAL) with target ^{27}Al and expected limit:

$$R_{\mu e} < 6 \times 10^{-17}$$

FNAL Proposal Carey, R., et al. (Mu2e) (2008), "Proposal to search for $\mu - n \rightarrow e - n$ with a single event sensitivity below 10^{-16}

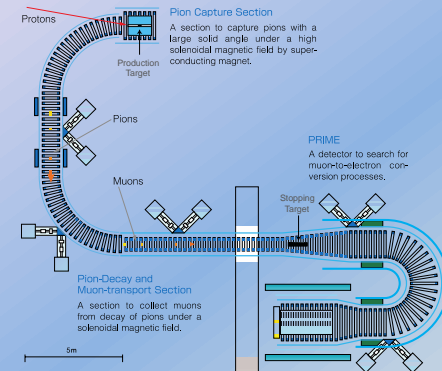


2). COMET (J-PARC) stopping target ^{27}Al

$$R_{\mu e} < 6 \times 10^{-17}$$

3). PRISM/PRIME (J-PARC)

[Y. Kuno, AIP Conf. Proc. 542 (2000) 220]



Upper limits of other similar processes

Upper limits from the reaction $\mu \rightarrow e \gamma$

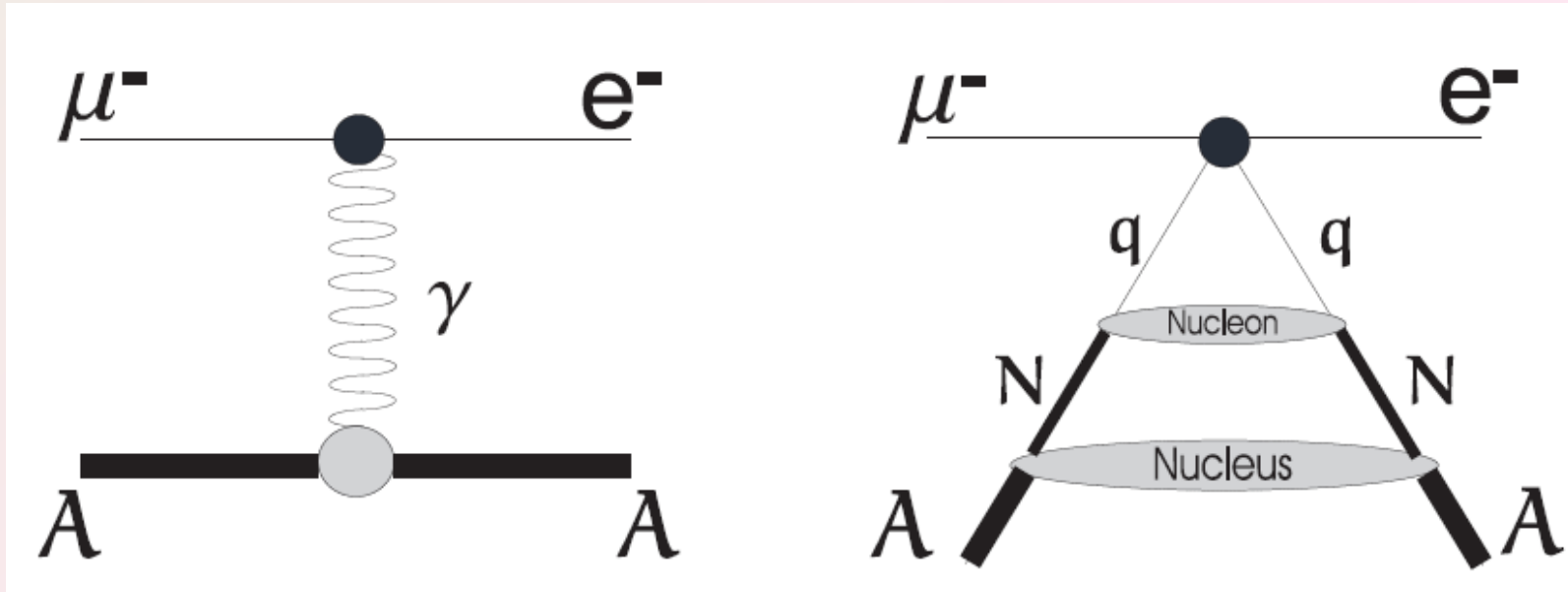
- $\mu \rightarrow e \gamma$ MEGA (PSI): $R_{\mu e \gamma} < 1.2 \times 10^{-11}$ (1999)
- $\mu \rightarrow e \gamma$ MEG (PSI): $R_{\mu e \gamma} < 2.4 \times 10^{-12}$ (2010)
- $\mu \rightarrow e \gamma$ MEG prop: $R_{\mu e \gamma} < 1.0 \times 10^{-13}$ (2010)

Upper limits from the reaction $\mu \rightarrow e e e$ ($\mu \rightarrow 3e$)

- $\mu \rightarrow 3e$ (PSI) sensitivity goal: $\alpha \times 10^{-14}$

The theory of μ -e conversion

We distinguish between Long-range (**Photonic**) and Short-distance (**Non-photonic**) Nuclear-level diagrams contributing to μ -e conversion



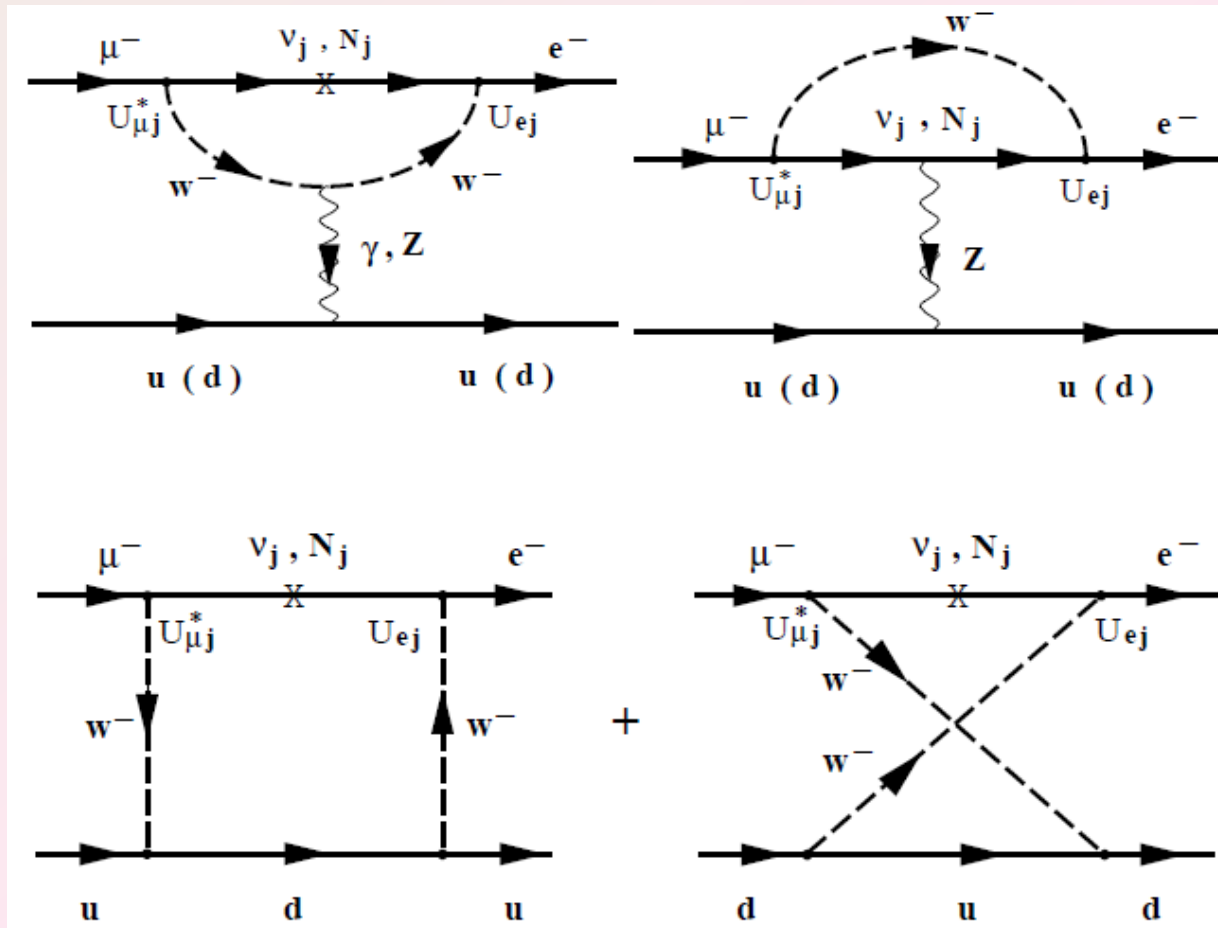
Photonic (Long distance)

Non-photonic (Short distance)

Nuclear-level diagrams contributing to μ -e conversion

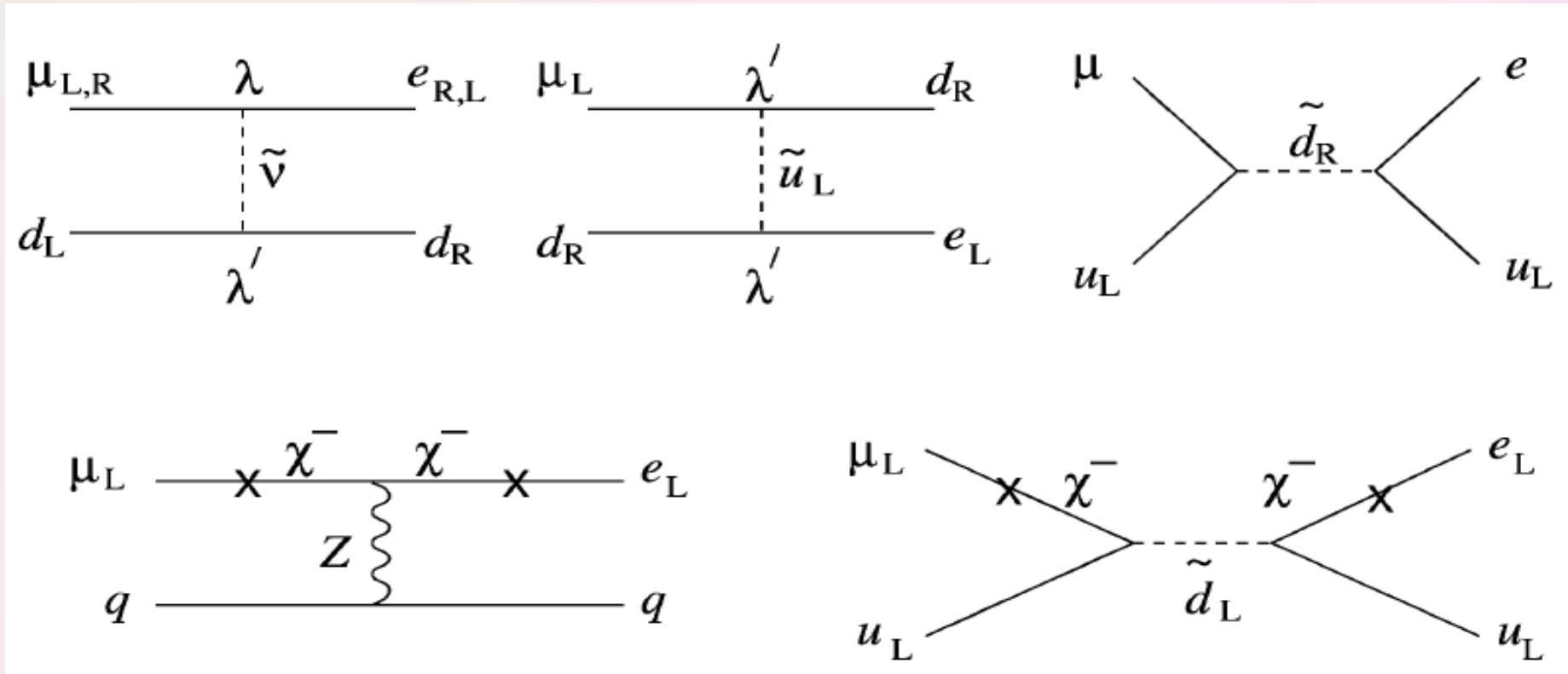
Main contributions to μ - e conversion

In neutrino mixing models, the **LNV** arises from penguin photon (γ) and **Z** exchange as well as box diagrams with W-exchange



R-parity violating diagrams of μ - e process

The μ - e process may occur due to exchange of scalar particles as exotic Higgs scalars, s-quarks, s-leptons, etc. The tree level R -parity violating SUSY diagrams are:



Top: Diagrams originating from the trilinear λ, λ' terms in the relevant super-potential.

Bottom: Diagrams originating from the chargino–charged lepton mixing

Nucleon-level Lagrangian for μ -e conversion

$$\mathcal{L}_{eff}^N = G_a \left[\sum_{A,B} j_\mu^A \left(\alpha_{AB}^{(0)} J_{(0)}^{B\mu} + \alpha_{AB}^{(3)} J_{(3)}^{B\mu} \right) + \sum_{C,D} j^C \left(\alpha_{CD}^{(0)} J_{(0)}^D + \alpha_{CD}^{(3)} J_{(3)}^D \right) + \left(j_{\mu\nu} (\alpha_T^{(0)} J_{(0)}^{\mu\nu} + \alpha_T^{(3)} J_{(3)}^{\mu\nu}) \right) \right], \quad a = \text{ph, nph}.$$

Hadronic current components

$$\begin{aligned} J_{(k)}^{V\mu} &= \bar{N} \gamma^\mu \tau_k N, & J_{(k)}^{A\mu} &= \bar{N} \gamma^\mu \gamma_5 \tau_k N, & J_{(k)}^{\mu\nu} &= \bar{N} \sigma^{\mu\nu} \tau_k N \\ J_{(k)}^S &= \bar{N} \tau_k N, & J_{(k)}^P &= \bar{N} \gamma_5 \tau_k N. \end{aligned} \quad N = \{p, n\}$$

In general, the Vector and Axial Vector current components dominate

For coherent μ -e conversion, only the vector and scalar parts are needed (the axial and pseudoscalar nucleon currents couple to the nuclear spin and **for J=0 nuclei** they contribute only to incoherent transitions).

Particle model **LFV** coefficients

The **coefficients** $\alpha_{(\tau)AB}$ of the Lagrangian can be expressed in terms of the **LFV** parameters η_{AB} of the quark level as

$$\begin{aligned}\alpha_{IV}^{(0)} &= \frac{1}{2}(\eta_{IV}^{(u)} + \eta_{IV}^{(d)})(G_V^u + G_V^d), \\ \alpha_{IV}^{(3)} &= \frac{1}{2}(\eta_{IV}^{(u)} - \eta_{IV}^{(d)})(G_V^u - G_V^d),\end{aligned}$$

$$I = V, A.$$

$$\begin{aligned}\eta_{VV}^{(q)} &= \frac{1}{2}(F^L + F^R)(Z_L^q + Z_R^q) + \frac{1}{2}Q^q(D_q^L + D_q^R), \\ \eta_{AV}^{(q)} &= \frac{1}{2}(F^L - F^R)(Z_L^q + Z_R^q) + \frac{1}{2}Q^q(D_q^L - D_q^R).\end{aligned}$$



non-photonic

$$\begin{aligned}\eta_{VV}^{(q)} &= \frac{1}{2}Q^q(A_1^L + A_1^R), \\ \eta_{AV}^{(q)} &= \frac{1}{2}Q^q(A_1^L - A_1^R),\end{aligned}$$



photonic

The coherent branching ratio

The coherent channel ‘measured’ in experiments, in many models accounts for about the **90% of the total μ -e branching ratio**. In the non-relativistic reduction $R_{\mu e}$ reads

$$R_{\mu e}^{\text{coh}} = Q_a G_a^2 \frac{p_e E_e}{2\pi} \frac{\mathcal{M}_a^2}{\Gamma(\mu^- \rightarrow \text{capture})}$$

where

$$Q_a = |\alpha_{VV}^{(0)} + \alpha_{VV}^{(3)}\phi|^2 + |\alpha_{AV}^{(0)} + \alpha_{AV}^{(3)}\phi|^2$$

Q depends weakly on nuclear structure parameters via the ratio

$$\phi = (\mathcal{M}_p - \mathcal{M}_n) / (\mathcal{M}_p + \mathcal{M}_n)$$

Nuclear matrix elements:

$$\mathcal{M}_{p,n} = 4\pi \int (g_e g_\mu + f_e f_\mu) \rho_{p,n}(r) r^2 dr.$$

For the g_μ (top) and f_μ (bottom) 1s muon WFs (and g_e , f_e of electron WFs) we solve numerically the Dirac Equation with artificial neural network techniques taking into account relativistic effects and vacuum polarization corrections

Nuclear matrix elements for incoherent rate

The ME, **accumulating the nuclear aspects of μ -e conversion**, are approximated by factorizing out of the muon–nucleus overlap integral a suitably averaged muon wave function $\langle \Phi_{1S} \rangle$

$$\mathcal{M}_{\alpha}^{(\tau)} \approx f_{\alpha}^{\tau} \langle \Phi_{1S} \rangle \langle f | \sum_{j=1}^A \Theta_{\alpha}^{\tau}(j) e^{-i\mathbf{q} \cdot \mathbf{r}_j} | i \rangle \equiv f_{\alpha}^{\tau} \langle \Phi_{1S} \rangle M_{\alpha}^{(\tau)}$$

where

$$\Theta_{\alpha}^{\tau}(j) = \begin{cases} 1, & \text{isoscalar, scalar or vector, component } (\alpha = S, V \text{ and } \tau = 0), \\ \tau_{3j}, & \text{isovector, scalar or vector, component } (\alpha = S, V \text{ and } \tau = 1), \\ \sigma_j / \sqrt{3}, & \text{isoscalar axial-vector component } (\alpha = A \text{ and } \tau = 0), \\ \tau_{3j} \sigma_j / \sqrt{3}, & \text{isovector axial-vector component } (\alpha = A \text{ and } \tau = 1). \end{cases}$$

The nuclear ME are evaluated via the decomposition procedure leading to multipole-expansion operators

$$O_{S,V}^{JM}(\tau) = \delta_{IJ} \sqrt{4\pi} \sum_{i=1}^A \theta^{\tau}(i) j_l(qr_i) Y_M^l(\hat{\mathbf{r}}_i)$$

$$O_A^{JM}(\tau) = \sqrt{4\pi} \sum_{i=1}^A \theta^{\tau}(i) j_l(qr_i) [Y^l(\hat{\mathbf{r}}_i) \otimes \sigma_i / \sqrt{3}]_M^J$$

Fermi-type

Gamow-Teller

$$\theta^{\tau}(i) = \begin{cases} 1, & \text{for } \tau = 0, \\ \tau_{3i}, & \text{for } \tau = 1. \end{cases}$$

[T.S.K. NPA 683 (2001) 443]

Nuclear model calculations for incoherent rate

The **total incoherent μ -e conversion strength** is obtained by summing over the partial transition ME for all accessible final states induced by the multipole operators as

$$S_{\alpha} = \sum_f \left(\frac{q_f}{m_{\mu}} \right)^2 \sum_{JM} |\langle f | \hat{T}_{\alpha}^{JM} | i \rangle|^2, \quad \alpha = S, V, A$$

Where the multipole operators (compact form)

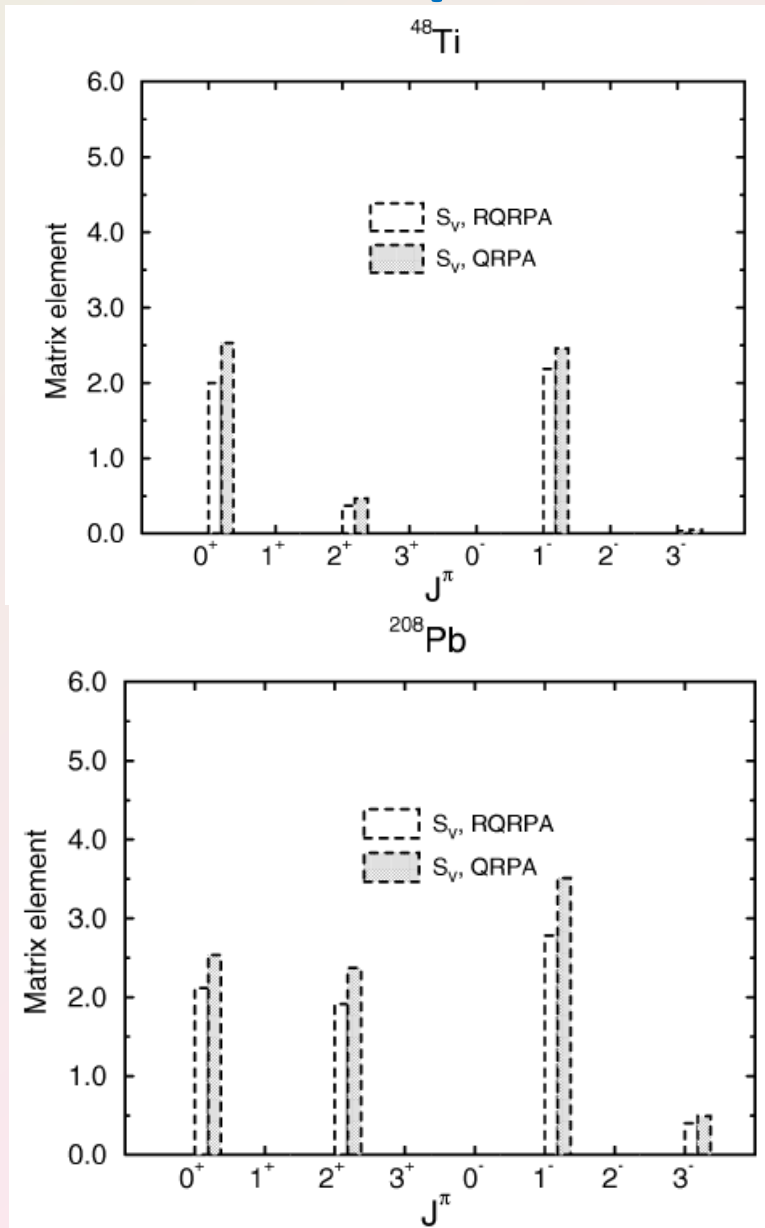
$$\hat{T}_{\alpha}^{JM} = \sum_{\tau} \beta_{\alpha}^{\tau} f_{\alpha}^{\tau} \hat{O}_{\alpha}^{JM}(\tau)$$

Nuclear structure calculations have been performed by using:

- (i) Shell Model,
- (ii) Various QRPA methods
- (iii) Relativistic Fermi Gas Model (use of the Lindhard function)

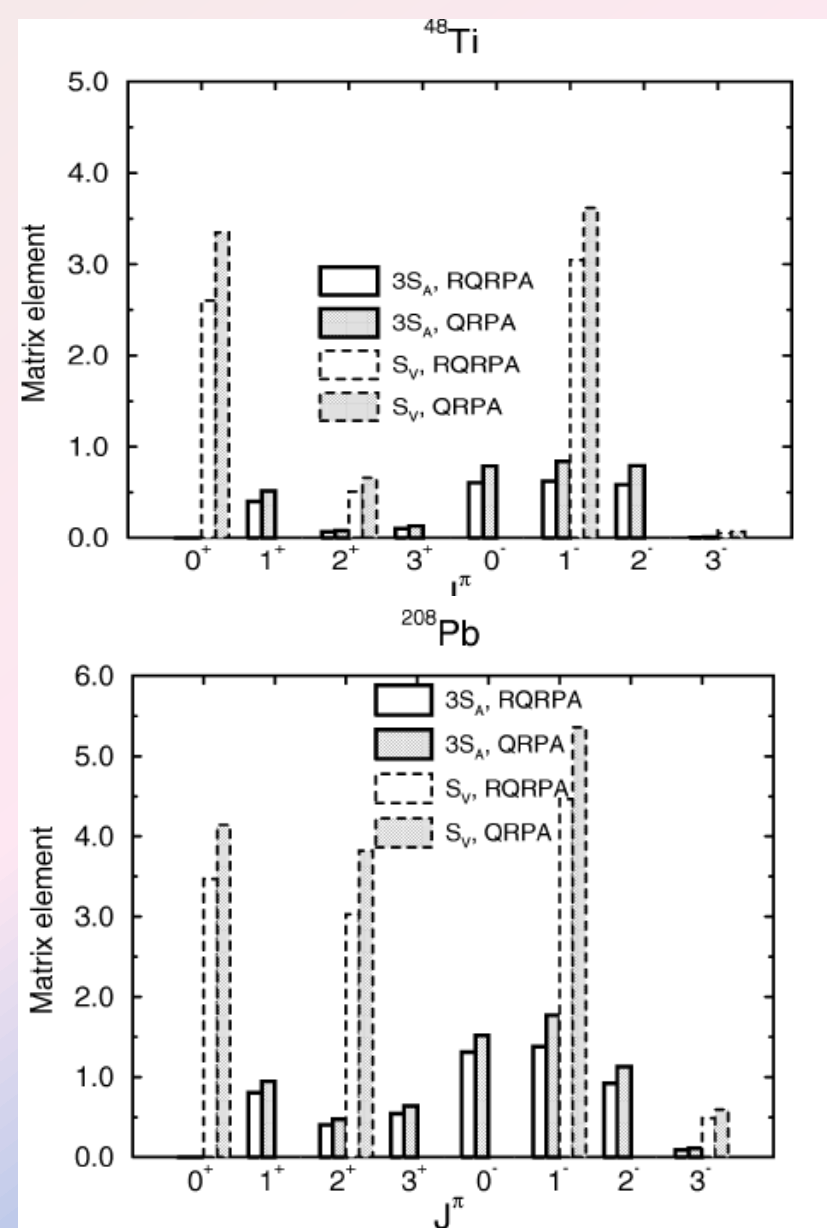
The results, in some important channels, are model dependent

Incoherent μ -e transition rate with QRPA methods



Photonic

TSK, Ren and Faessler, NPA 665(2000)183; *TSK*, NPA 683(2001)443



Non-Photonic

Shell model results

New limits for lepton-flavor violation from the $\mu^- \rightarrow e^-$ conversion in ^{27}Al

RAPID COMMUNICATIONS

NEW LIMITS FOR LEPTON-FLAVOR VIOLATION FROM . . .

PHYSICAL REVIEW C **60** 062501

TABLE II. Shell model predictions for coherent, incoherent and total matrix elements for photonic and nonphotonic diagrams in ^{27}Al (in isospin formalism). The ratio $\eta \approx M_{\text{coh}}^2/M_{\text{tot}}^2$ is also shown ($M^2 = S_V + 3S_A$).

Mechanism	$S_A(\text{coh})$	$S_V(\text{coh})$	M_{coh}^2	$S_A(\text{inc})$	$S_V(\text{inc})$	M_{inc}^2	M_{tot}^2	$\eta(\%)$
γ exchange	0.000	64.60	64.60	0.000	1.54	1.54	66.13	97.7
W exchange	0.002	512.10	512.11	2.94	10.42	19.26	531.36	96.4
SUSY Z exchange	6.71	392.36	412.47	116.72	10.61	360.76	773.23	53.3



$$\eta = \Gamma_{\text{coh}}(\mu \rightarrow e^-) / \Gamma_{\text{tot}}(\mu \rightarrow e^-) \approx M_{\text{coh}}^2 / M_{\text{tot}}^2$$

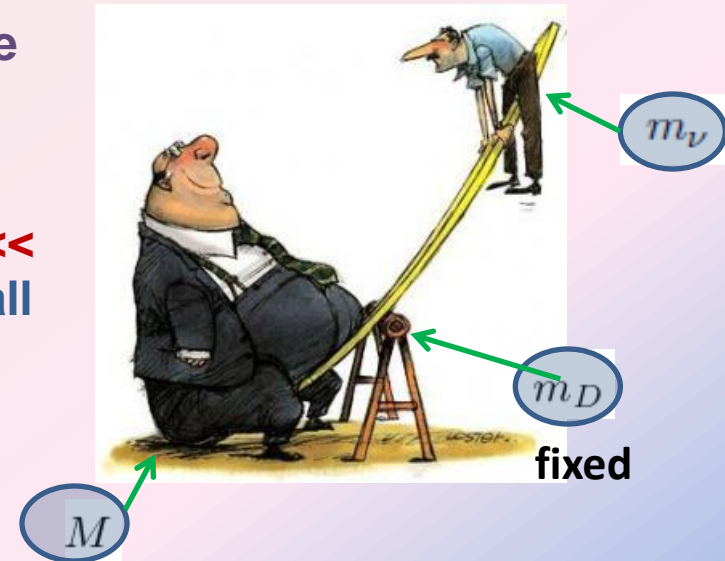
[T. Siiskonen, J. Suhonen and **TSK**, PRC 60 (1999)R 062501]

Limits on the inverse Seesaw Model parameters

In the inverse seesaw model LFV and the μ -e conversion rates appear to be enhanced

The μ and M are free parameters (assume $\mu, m_D \ll M$ and choose m_D, M so that the $m_{\nu,L}$ becomes small and $m_{N,R}$ becomes extremely heavy)

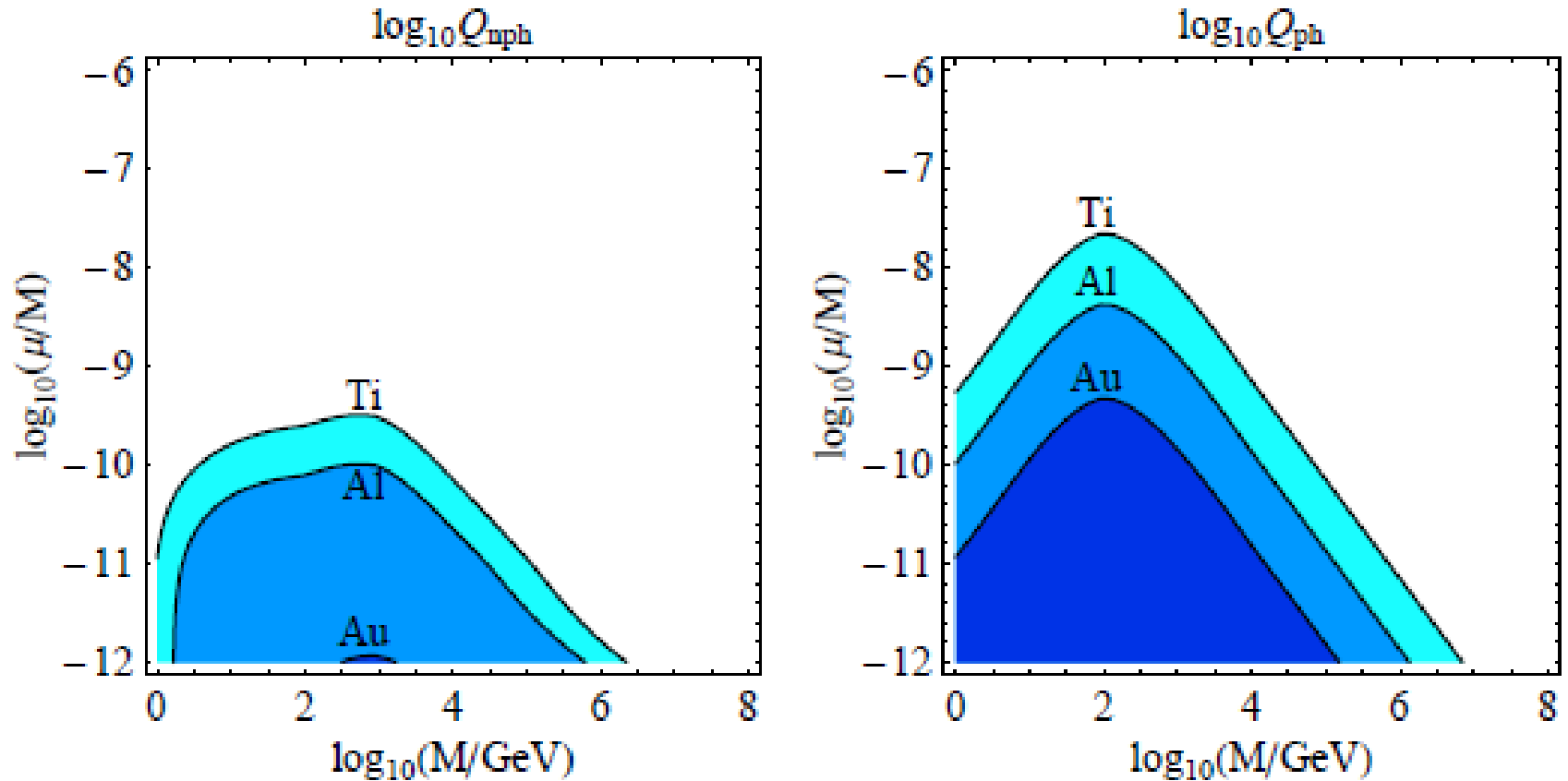
[Deppisch, *T.S.K.* and Valle, NPB 752 (2006) 80]



Parameter	Present limits (PSI) ^{197}Au	Expected limits (MECO) ^{27}Al	Expected limits (PRISM) ^{48}Ti
Q_{ph}	$1.96 \cdot 10^{-16}$	$2.68 \cdot 10^{-18}$	$8.39 \cdot 10^{-20}$
Q_{nph}	$4.45 \cdot 10^{-15}$	$6.67 \cdot 10^{-19}$	$1.84 \cdot 10^{-20}$

Upper bounds on the parameters Q_{ph} and Q_{nph} inferred from the latest SINDRUM II data on μ -e in ^{197}Au and the expected sensitivities of MECO (BNL) and PRIME (KEK) detectors with ^{27}Al and ^{48}Ti stopping targets, respectively.

Limits on M, μ parameters (Inverse Seesaw)



Present and expected limits on the model parameters M and μ/M . The shaded areas are excluded by the bounds on Q_{nph} (left panel) and Q_{ph} (right panel)

Realistic neutrino-nucleus cross sections

Use of QRPA method to carry out original calculations in:

- i) State-by-state calculations for: $d^2\sigma/d\Omega d\omega$, $d\sigma/d\Omega$, $d\sigma/d\omega$, σ_{tot}
- ii) To study the contributions of individual multipolarities
- iii) Study the dominance of various hadronic current operators in σ_{tot}

V.Chasioti, TSK, NPA 829 (2009) 234

V.Tsakstara, T.S.K, *PRC* 83 (2011) 054612, 84 (2011) 064620

K.Balasi, E. Ydrefors, TSK, NPA 866(2011)67, NPA868-869(2011)82

V.Tsakstara, T.S.K, *PRC*, *Submitted*

The goal is to:

Investigate responses to ν -spectra of promising neutrino-detectors:

- i) Te, Cd, Zn –isotopes (COBRA, CUORE) K. Zuber, *Phys. Lett. B* 519, 1 (2001)
- ii) Mo-isotopes (MOON exp., Japan) H. Ejiri, *Phys. Rep.* 338, 265 (2000).
- iii) Ar (IKARUS exp. at Gran Sasso)

Y. Giomataris and J. D. Vergados, *Phys. Lett. B* 634, 23 (2006).

J. D. Vergados and Y. Giomataris, *Phys. At. Nucl.* 70, 140 (2007).

Neutral current ν -Nucleus reactions cross sections

The calculations start from (Walecka-Donnelly method)

$$\frac{d^2\sigma_{i\rightarrow f}(\omega, \theta, \phi, \varepsilon_\nu)}{d\Omega d\omega} \Big|_{\nu/\bar{\nu}} = \delta(E_f - E_i - \omega) \frac{2G^2 \varepsilon_f^2 \cos^2(\theta/2)}{\pi(2J_i + 1)} [\mathcal{C}_V + \mathcal{C}_A \mp \mathcal{C}_{VA}]$$

where

$$\begin{aligned} \mathcal{C}_{V(A)} = & \sum_{J=0}^{\infty} |\langle J_f || \widehat{M}_J^{(5)}(q) + \frac{\omega}{q} \widehat{L}_J^{(5)}(q) || J_i \rangle|^2 \\ & + \sum_{J=1}^{\infty} \left(-\frac{q_\mu^2}{2q^2} + \tan^2 \frac{\theta}{2} \right) \left[|\langle J_f || \widehat{T}_J^{mag(5)}(q) || J_i \rangle|^2 \right. \\ & \left. + |\langle J_f || \widehat{T}_J^{el(5)}(q) || J_i \rangle|^2 \right]. \end{aligned}$$

$$\begin{aligned} \mathcal{C}_{VA} = & 2 \tan \frac{\theta}{2} \left[-\frac{q_\mu^2}{q^2} + \tan^2 \frac{\theta}{2} \right]^{1/2} \\ & \times \sum_{J=1}^{\infty} \Re \langle J_f || \widehat{T}_J^{mag}(q) || J_i \rangle \langle J_f || \widehat{T}_J^{el}(q) || J_i \rangle^* \end{aligned}$$

$$\begin{aligned} q \equiv |\mathbf{q}| &= [\omega^2 + 4\varepsilon_i(\varepsilon_i - \omega) \sin^2(\theta/2)]^{1/2} \\ q_\mu^2 \equiv q_\mu q^\mu &= -4\varepsilon_i(\varepsilon_i - \omega) \sin^2(\theta/2). \end{aligned}$$

$$\omega = E_f - E_i = \varepsilon_i - \varepsilon_f$$

[1] T. W. Donnelly and J. D. Walecka, *Nucl. Phys. A* **274**, 368 (1976).

[2] T. W. Donnelly and R. D. Peccei, *Phys. Rep.* **50**, 1 (1979).

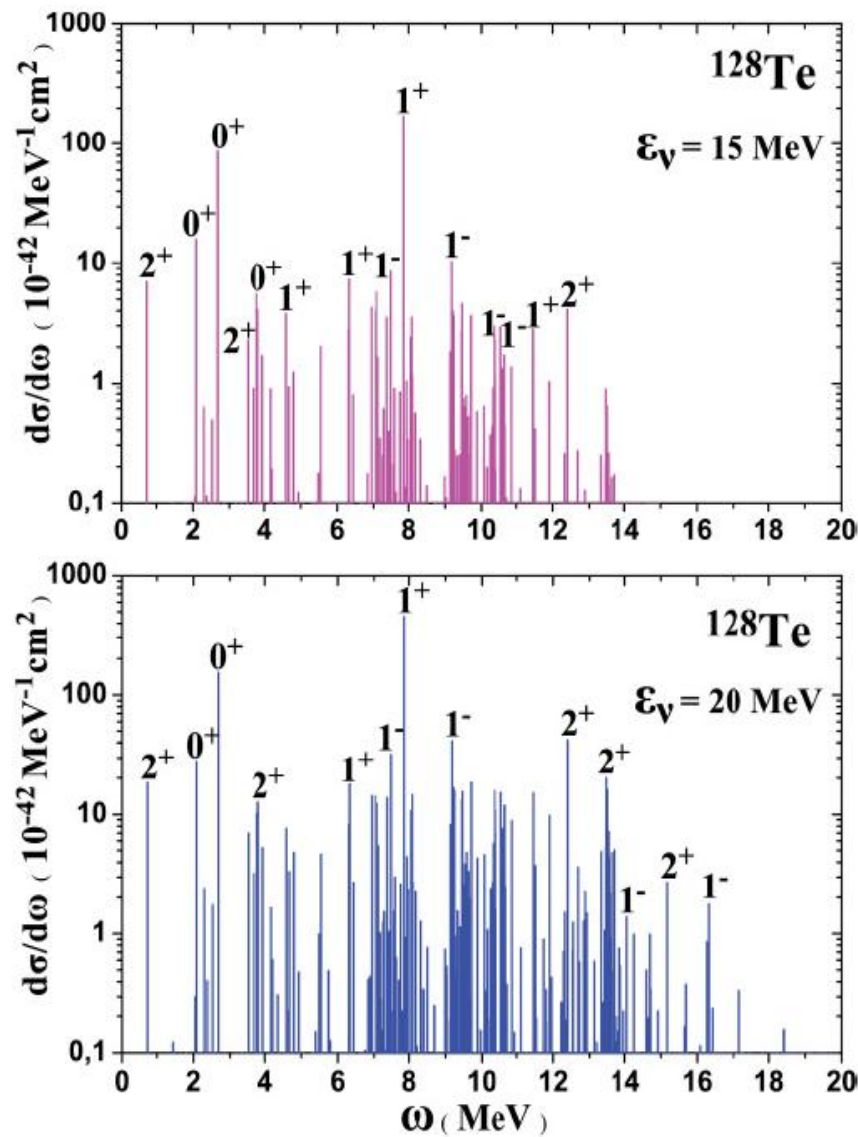


FIG. 2. (Color online) Differential cross section $d\sigma/d\omega(\omega)$ as a function of the excitation energy ω for the nucleus ^{128}Te . The incoming neutrino energy was $\varepsilon_v = 15 \text{ MeV}$ (upper panel) and $\varepsilon_v = 20 \text{ MeV}$ (lower panel).

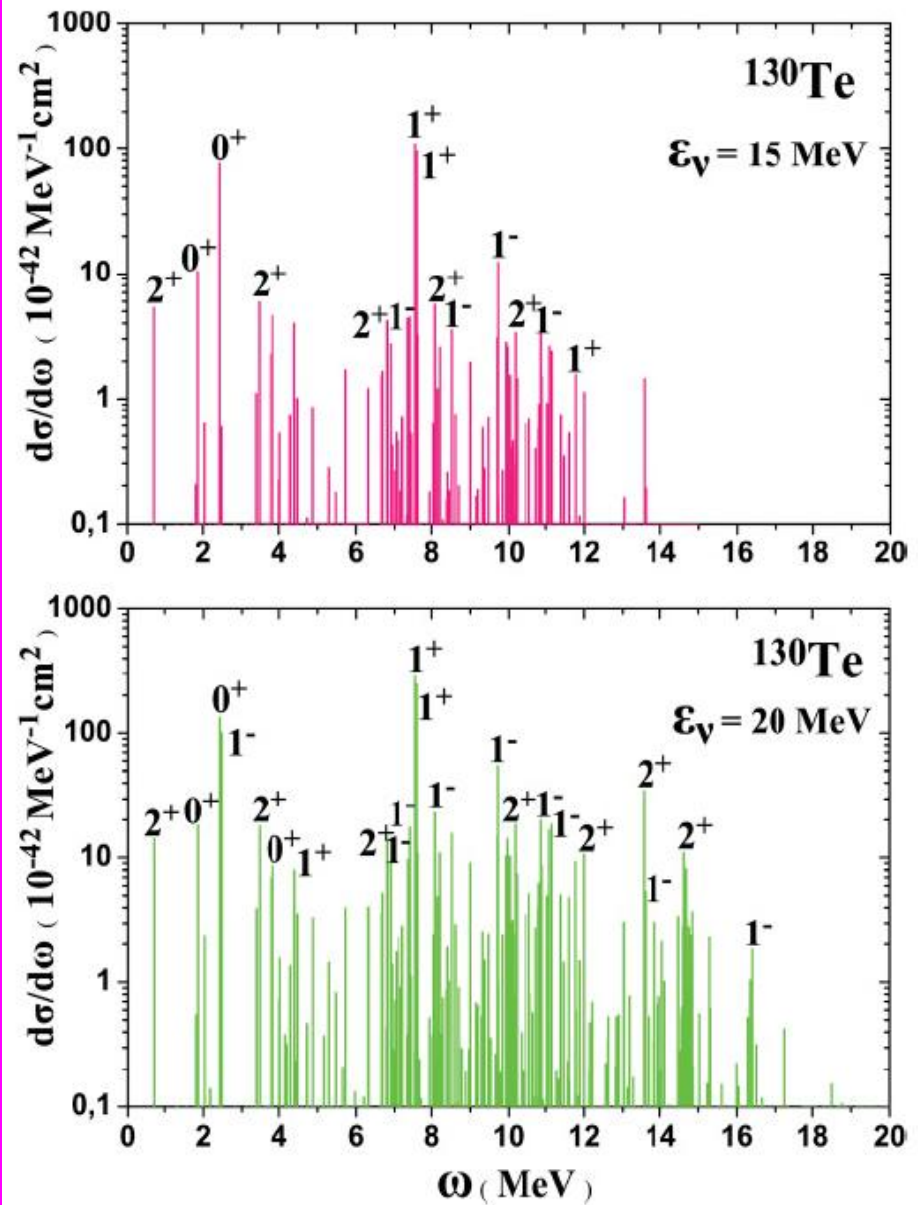


FIG. 3. (Color online) Same as in Fig. 2 but now for the ^{130}Te isotope.

μ -e conversion & exotic ν -nucleus processes

The **LF** and/or **L** Violating reactions in nuclei are now revisited by the Ioannina group (use of advantageous numerical methods, more reliable nuclear forces)

$$\mu_b^- + (A, Z) \rightarrow e^- + (A, Z)^*$$

FCNC ν -Nucleus reactions and μ -e conversion can be described within the same particle physics model (**inverse seesaw model**)

$$\nu_\alpha + (A, Z) \rightarrow \nu_\beta + (A, Z)^*$$

$$\tilde{\nu}_\alpha + (A, Z) \rightarrow \tilde{\nu}_\beta + (A, Z)^*$$

We have ready to submit a proposal by the end of June, 2012, to study (among others) **FCNC reactions in nuclei** and their impact to Astrophysical phenomena (stellar evolution, etc)

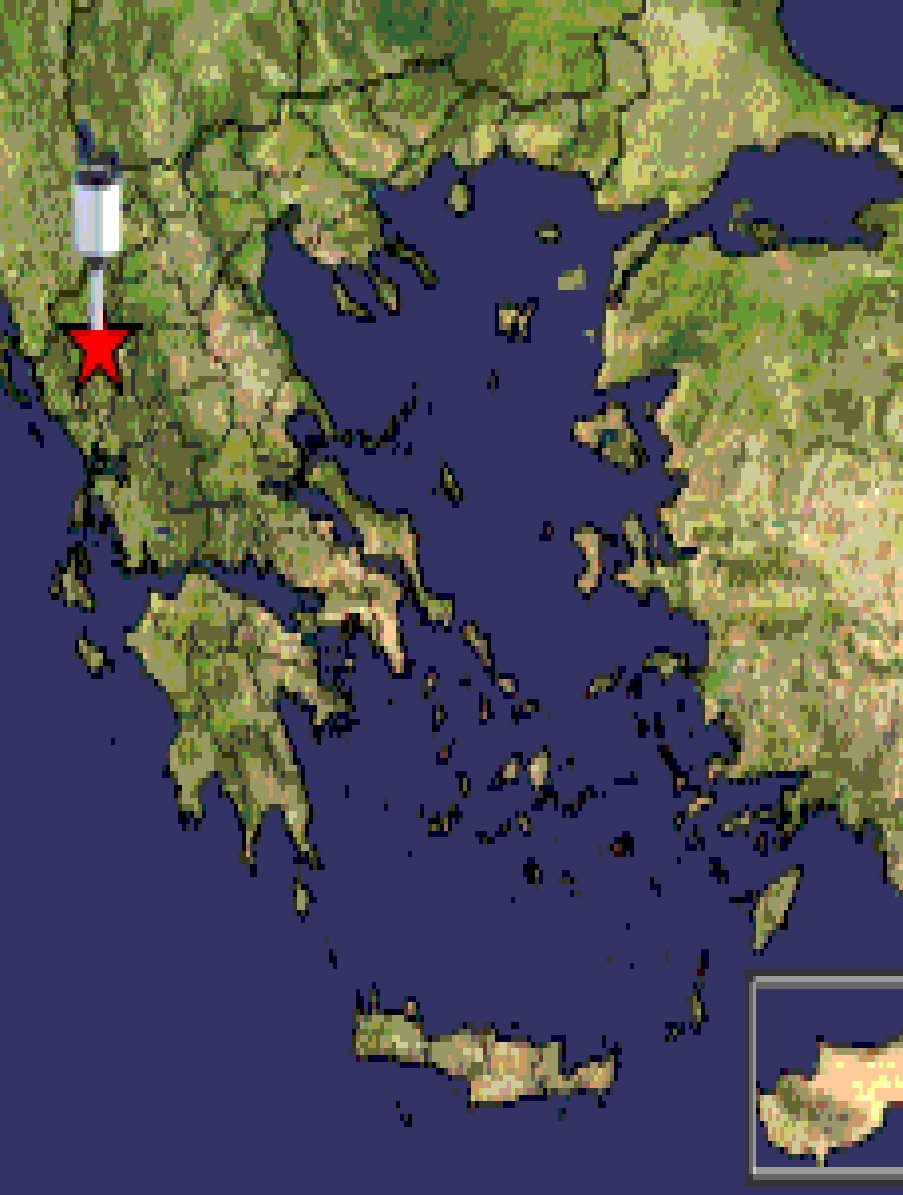
Summary - Conclusions - Outlook

- The μ -e conversion is a **powerful probe for studying FCNC interactions** and putting robust constraints in various LFV parameters of non-standard theories
- By studying **FCNC** processes of **charged and neutral leptons** we may deepen our knowledge of LFV interactions
- Nuclear physics aspects and reliable transition ME calculations can compliment the relevant experiments

Ioannina, the city of Silver and Gold



Thank you for your attention



Thank you for your attention

Coherent and incoherent nuclear transition ME

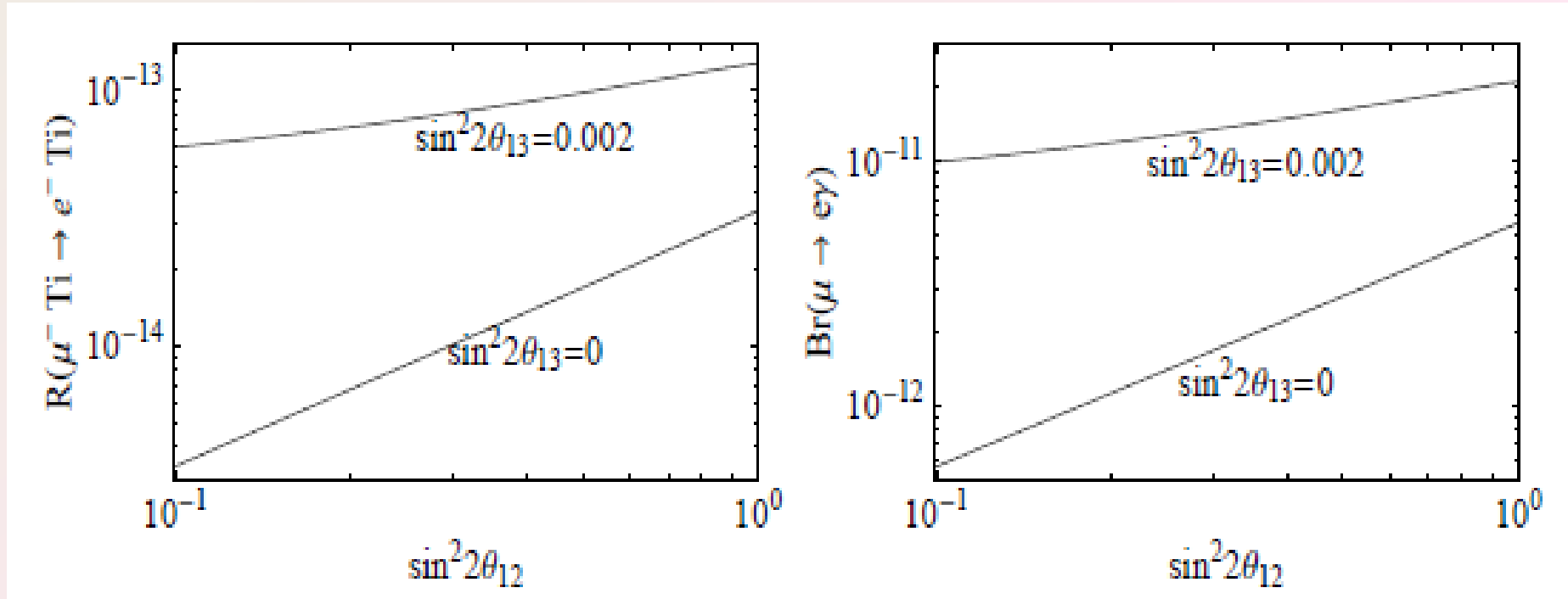
Photonic

RQRPA					QRPA			
Nucleus	M_{incoh}^2	M_{coh}^2	M_{total}^2	η	M_{incoh}^2	M_{coh}^2	M_{total}^2	η
^{48}Ti	4.60	127.2	131.8	97%	5.51	117.7	123.21	96%
^{60}Ni	3.84	171.1	174.94	97%	4.48	149.4	153.88	97%
^{72}Ge	5.54	199.1	204.64	97%	6.94	169.9	176.84	96%
^{112}Cd	6.48	285.7	292.18	98%	8.14	222.6	230.74	96%
^{162}Yb	9.63	393.3	402.93	98%	13.52	283.8	297.32	95%
^{208}Pb	7.26	415.6	422.86	98%	8.97	379.4	388.37	98%

Non-photonic

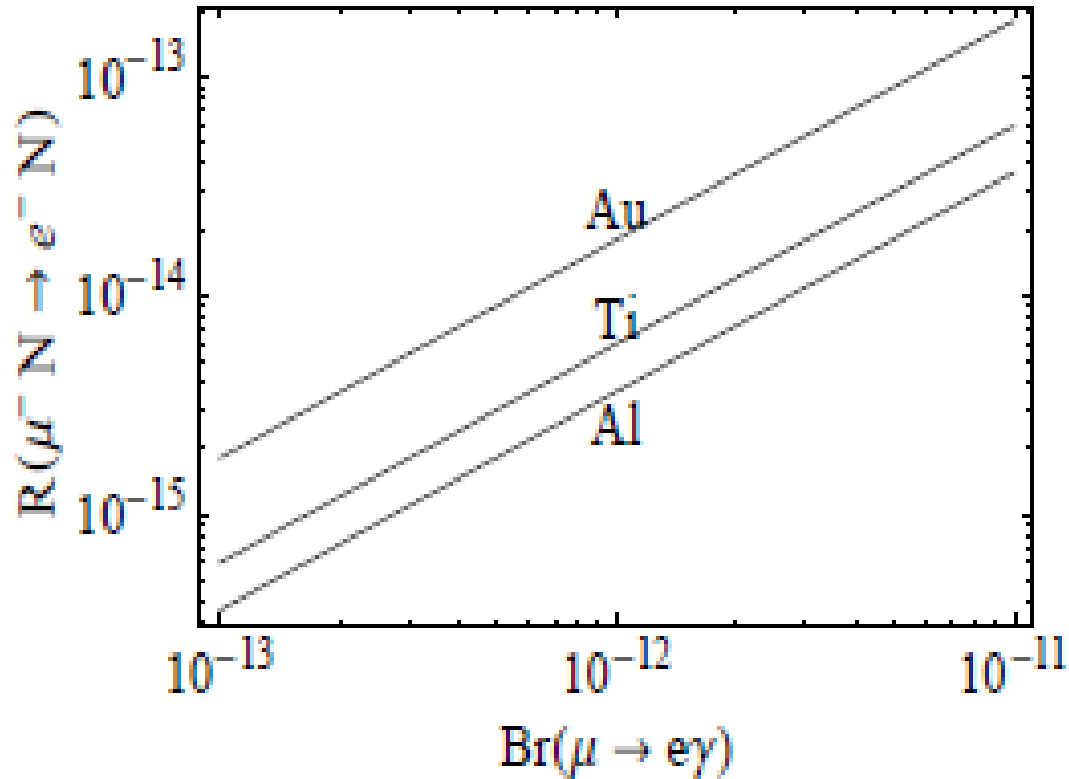
RQRPA					QRPA			
Nucleus	M_{incoh}^2	M_{coh}^2	M_{total}^2	η	M_{incoh}^2	M_{coh}^2	M_{total}^2	η
^{48}Ti	8.66	341.8	350.46	98%	10.89	316.3	327.19	97%
^{60}Ni	8.47	454.1	462.59	98%	10.15	396.6	406.75	98%
^{72}Ge	11.06	558.9	569.96	98%	14.31	477.1	491.41	97%
^{112}Cd	13.81	810.2	824.01	98%	18.04	631.3	649.34	97%
^{162}Yb	19.42	1089.1	1108.52	98%	28.40	785.9	814.3	97%
^{208}Pb	17.12	1180.4	1197.52	99%	20.77	1077.8	1098.57	98%

Inverse Seesaw model results



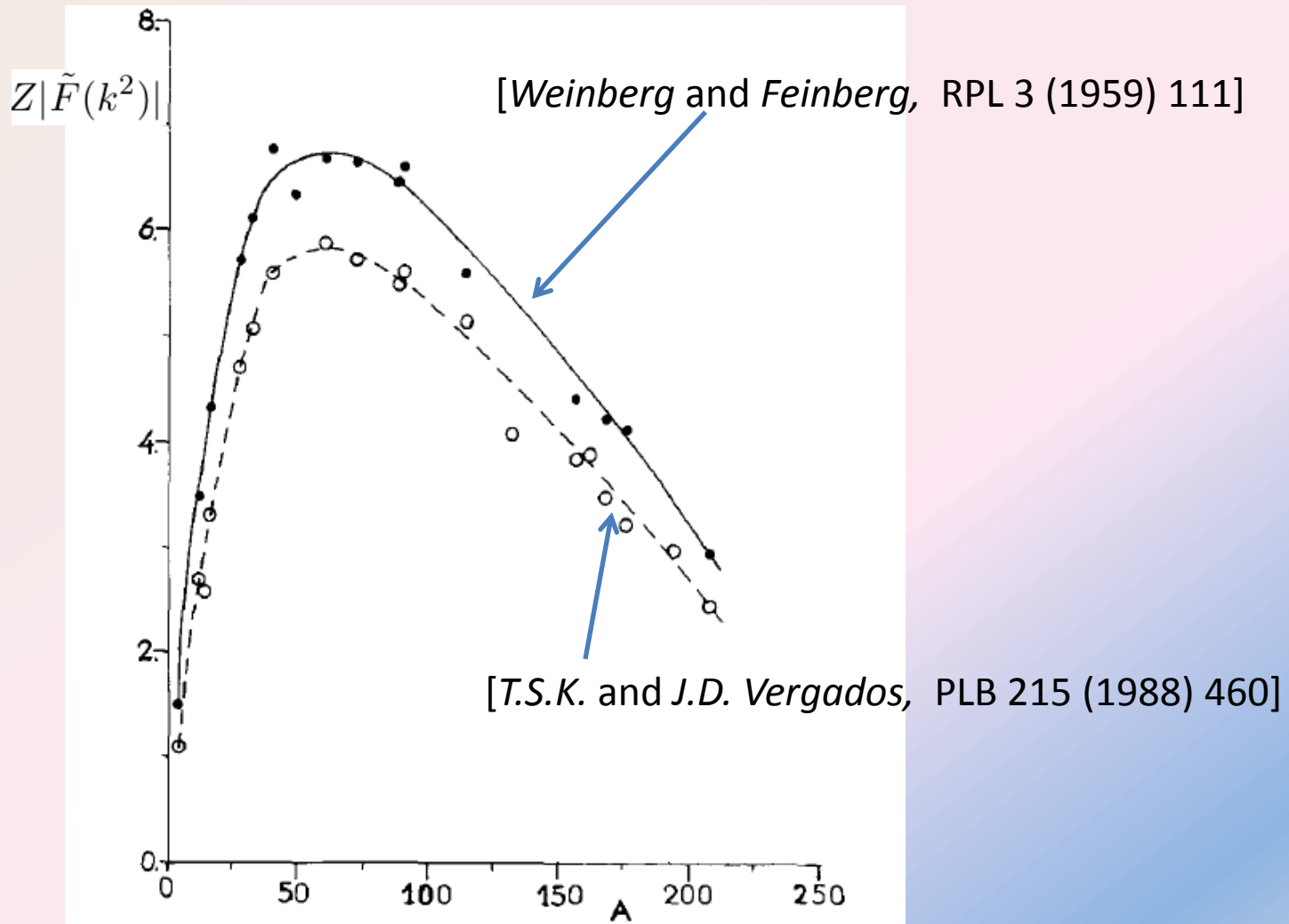
Relation of branching ratios for μ -e conversion (left panel) and μ -e (right panel) with the solar neutrino mixing angle, for different values of ϑ_{13} . The inverse seesaw parameters are given by: $M = 100 \text{ GeV}$, $\mu = 10 \text{ eV}$.

Inverse Seesaw model results



Correlation between nuclear μ - e conversion and $\mu \rightarrow e$ decay in the inverse seesaw model.

Form factor vs. mass number



The calculated values take into account the finite size of the nucleon. For comparison the respective quantity as estimated by Weinberg and Feinberg is also shown (dashed line). The two curves indicate similar variations with their maximum value in the Cu region